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(54) **Method and apparatus for direct oxygen injection with a reactant stream into a fluidized bed reactor**

(57) A system provides an oxygen-bearing gas and gaseous reactant stream to a fluidized bed reactor using a sparger to entrain the oxygen-bearing gas into the reactant gas stream. A feed line couples the sparger to the reactor's fluidized bed and introduces the reactant gas stream and entrained oxygen-bearing gas directly into contact with the fluidized bed. A controller controls and maintains both the amount of oxygen-bearing gas and the gaseous reactant above an upper flammability limit, preferably with a safety margin of at least 10%.

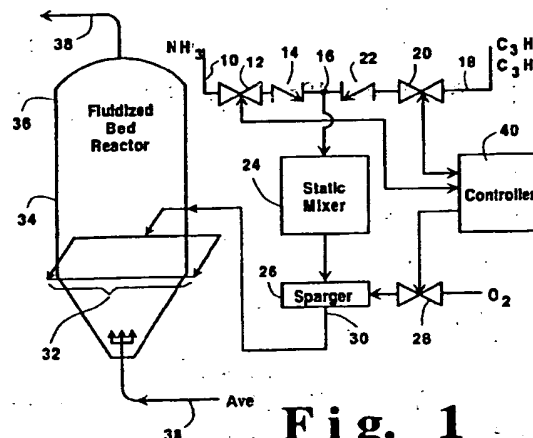


Fig. 1

## Description

### FIELD OF THE INVENTION

This invention relates to a method and apparatus for entraining an oxygen-bearing gas in a reactant stream which is fed to a fluidized bed reactor and, more particularly, for injection of oxygen into a reactant feed stream to a fluidized bed reactor that is employed in a maleic anhydride synthesis process.

### BACKGROUND OF THE INVENTION

The production of anhydrides involves partial oxidation of an appropriate hydrocarbon in the presence of a suitable catalyst. Commercial maleic anhydride production employs feeds of an appropriate gaseous reactant stream such as butane, butene or benzene into a partial oxidation reactor where, in the presence of air/oxygen and a suitable catalyst, maleic anhydride is produced with lower amounts of other oxygenates and carbon oxides. In most cases, butane is the preferred feedstock. When butane is used as the starting raw material, the reactor is often a fluidized bed reactor which includes a separate air injection conduit for introduction of air into the fluidized bed.

To provide oxygen for the conversion of butane to maleic anhydride, the prior art has suggested the addition of oxygen or oxygen-containing gas directly to the feed flow or as a separate feed to the reactor. Such teachings can be found in U.S. Patent No. 3,899,516 to Dickason, U.S. Patent No. 4,668,802 to Contractor, U.S. Patent Nos. 4,987,239 and 5,126,463 to Ramachandran et al. None of the aforesaid patents provides any teaching that an oxygen deficiency can occur in a fluidized bed reactor at the point of reactant feed introduction. Dickason teaches adding substantially pure oxygen directly to the reactor at high butane concentrations. Contractor teaches the use of a transport bed with air, oxygen enriched air, or oxygen in the regeneration zone. Both Ramachandran patents teach that when pure oxygen feed is present in the partial oxidation reactor, that a gaseous flame suppressor mixture be utilized, e.g., carbon dioxide or a substantially unreacted hydrocarbon. As a result, both Ramachandran patents provide further apparatus downstream from the partial oxidation reactor to recover and recycle the carbon dioxide and unreacted hydrocarbon feed.

U.S. Patent No. 3,661,165 to Rainbird et al. discloses a sparger valve for mixing oxygen with gaseous hydrocarbons in a process stream. The Rainbird et al. sparger valve includes a number of jets facing downstream within the hydrocarbon gas flow. The jets introduce oxygen at a jet velocity that is substantially higher than the velocity of the hydrocarbon gas. Variations in oxygen mass flow are achieved by varying the area of the jet orifices, while maintaining a predetermined pressure drop across the orifices.

U.S. Patent No. 3,702,619 to Son discloses a process and apparatus for dispensing an gaseous stream into another gaseous stream in an inline mixing apparatus.

U.S. Patent No. 5,356,213 to Arpentinier describes a further sparger design which is positioned coaxially with respect to the axis of a channel containing a feed stream. Radial vanes are employed in the sparger to inject gas in a substantially radial direction towards the outside of the feed flow so as to enable a mixing of the injected gas with the feed flow gas.

The above noted prior art includes no teaching of fluidized bed reactor performance penalties which occur as a result of oxygen deficiencies at points of feed stream introduction. Further, the prior art, while including teachings regarding the introduction of oxygen-bearing gases at various points in a process, includes no teachings of how such an introduction can be accomplished in a manner to assure process safety.

Accordingly, it is an object of this invention to provide an improved system for enabling an oxygen bearing gas to be combined with a gaseous reactant feed flow to a fluidized bed reactor.

It is another object of this invention to provide an improved system and method for combining an oxygen-bearing gas and gaseous reactants in a manner to avoid explosions, deflagration or other anomalous effects in the process.

It is yet another object of this invention to provide an improved method and system for addition of oxygen to butane in a fluidized bed reactor wherein oxygen deficiencies at feed flow entries are voided.

### SUMMARY OF THE INVENTION

A system provides an oxygen-bearing gas and a gaseous reactant stream to a fluidized bed reactor. A sparger causes an entraining of the oxygen-bearing gas into the reactant gas stream. A feed line couples the sparger to the reactor's fluidized bed and introduces the reactant gas stream and entrained oxygen-bearing gas directly into contact with the fluidized bed. A controller controls both the amount of oxygen-bearing gas and the gaseous reactant so that, at the point of feed injection, the fluidized bed catalyst does not experience an oxygen deficiency. To assure safety, the reactant content of the combined feed and oxygen stream is maintained above an upper flammability limit, preferably with a safety margin of at least 10%. In one embodiment, the system enables the production of maleic anhydride from a feed stream comprising butane and oxygen.

### BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram of a system that embodies the invention hereof.

Fig. 2 is a sectional view of a feed pipe which includes a sparger for introducing oxygen into a gaseous

ous feed stream.

Fig. 3 is a schematic view of a pair of adjacent jets of the sparger of Fig. 2.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

While the invention will hereafter be described in the context of fluidized bed maleic anhydride production process, those skilled in the art will realize that it is equally applicable to other processes which entrain an oxygen-containing gas with a reactant stream feed to a fluidized bed reactor. In Fig. 1, a system is shown for producing maleic anhydride using a fluidized bed partial oxidation process. A conduit 10 provides a flow of butane through a control valve 12, a check valve 14 to a sparger 26. An oxygen source is connected via a control valve 28 to sparger 26.

Sparger 26 thereby enables oxygen to be entrained into the mixed reactant gas stream and to pass via conduit 30 to feedlines 32. Feedlines 32 are in direct contact with a fluidized bed 34 which comprises a particulate catalyst that facilitates a reaction occurring between the butane and oxygen constituents to produce maleic anhydride. That product is output from reactor 36 via conduit 38 where it is subjected to further processing. At the bottom of reactor 36 is an air feed 38 which provides additional oxygen for the reaction.

A controller 40 includes control connections to each of valves 12, 20 and 28 and serves to control reactant feeds therethrough in accordance with sensed process conditions. While a single controller 40 is shown in the Fig. 1, those skilled in the art will realize that a plurality of controllers can be used to control the respective valves and other control entities. The process inputs to controller 40 are not shown in the Figs. 2 and 3.

Controller 40 (under operator control) assures that sufficient oxygen is injected by sparger 26 into the feed stream to assure, at the points of injection within fluidized bed reactor 36, that sufficient oxygen is present to prevent an oxygen deficiency at such points of injection. The controller further assures that the mixed concentration of reactants and oxygen is kept above an upper flammability limit (UFL) of the mixture. An acceptable safety margin of at least 10%, and preferably 25%, should be maintained.

The direct injection of oxygen with the reactants enables a concentration of oxygen at the region of feed injection which enables both a yield improvement and lifetime extension. Air flow into reactor 36, via conduit 38 also is adjusted to assure that the proper amount of oxygen is entrained within the reactor fluidized bed to enable optimum reaction conditions to be achieved. It is vital to the invention that plural oxygen supplies be provided to fluidized bed reactor 36, one supply assuring a proper oxygen concentration at the immediate regions of feed injection and the second oxygen supply assuring overall appropriate oxygen availability within the fluid-

ized bed to enable proper reaction conditions to be achieved.

As indicated above, the feed flow of oxygen through sparger 26 is maintained at a level to assure that the upper flammability limit of the mixed reactant gas stream is exceeded. The upper and lower flammability limits (UFL and LFL) for a butane feed stream in 100% oxygen is about 49.0 and 1.8, respectively, at 3.1 kg/cm<sup>2</sup>g, 440°C.

Sparger 26 is shaped to allow its injectors to be arranged in pattern that achieves effective oxygen distribution throughout the reactant gas flow. The injectors are further positioned so as to prevent interaction of flammable mixtures which occur within the feed stream. In Fig. 2, sparger 26 is positioned within conduit 30 and is preferably shaped in the form of a single ring 50 that is positioned normal to the feed gas flow. To achieve good gas distribution, the inner and outer diameters of ring 50 are set so that there is substantially equal gas flow in regions 52 and 54, respectively. This arrangement assures that a low pressure area is not formed in the feed pipe within the ring of injectors (which would draw together the jets, cause a coalescence thereof and create a severe problem in the event of an ignition of one of the jets). Thus, the effective cross-sectional areas of regions 52 and 54 are made approximately equal by appropriate sizing of ring 50.

Within ring 50 is a channel 56 which communicates with valve 28 (see Fig. 1) via inlet 58. A plurality of fixed jets 60 are positioned about ring 50 and are oriented so as to direct oxygen outflow from channel 56 in a downstream direction within conduit 30.

A sectional view of a pair of jets 60' and 60" is shown in Fig. 3. Oxygen flows out of jets 60' and 60" and creates substantially pure oxygen regions 70 and 72. The mixed reactant feed gas is present in regions 74, 74' and 74". Within regions 76 and 78 (cross-hatched), a mixture of oxygen and reactants occurs which is within the flammable ranges. Further downstream (regions 80 and 82), the gaseous mixture is non-flammable, even though oxygen bearing.

The spacing D between adjacent jets 60' and 60" is adjusted so that the flammable regions 76 and 78 do not interact. The limitation of jet-to-jet interaction reduces the probability of a once ignited jet causing ignition of another jet and of the jets coalescing to form a single jet with a large flame volume. The orifices of adjacent jets are thus placed so that neighboring regions of flammable gas mixture do not interact. Further, the mixed gas regions from adjacent jets intersect at a point beyond the farthest extent of the flammable regions. The risk of ignition is further reduced by lowering the total combined flammable volume contained within each oxygen jet. This is accomplished by minimizing the orifice diameter of each jet which, in turn, tends to maximize the number of orifices to accomplish a desired oxygen flow level.

The distance between a center of one orifice to the

center of an adjacent orifice is given by:

$$D > d_0 \{258.7 - \text{UFL}\} / (100 - \text{UFL})$$

where: D = center - center distance between orifices;  $d_0$  = orifice diameter;

UFL = upper flammability limit (in percent).

A risk of sustained jet deflagration is further reduced by insuring that the oxygen jet velocity is appreciably greater than both the velocity of the gaseous feed reactants and the flame velocity of a flammable oxygen reactant mixture. Such a jet velocity promotes flame blowoff, should flaming occur. To encourage blowoff, the initial oxygen jet velocity is preferably at least twice either the feed velocity of the reactant stream or flame velocity, whichever is greater. Further, the sparger is not to be constructed out of square shaped tube or to be supported with angle iron. Such structures include sharp angles which create eddies that can enhance flame stability.

Returning to Fig. 1, controller 40 operates valves 12, 20 and 28 to provide about four parts butane and ninety-six parts of air to fluidized bed reactor 36. The injection of oxygen, via valve 28 and sparger 26, enables a modest reduction in air flow via conduit 28. In addition to assuring that the combined reactant/oxygen flow in conduit 30 is in excess of the upper flammability level, it is preferred that the volumetric outflow from sparger 26 does not exceed a relative volumetric flow of 38% oxygen and 62% butane, more preferably, the volumetric outflow does not exceed a relative volumetric flow of 32% oxygen and 68% butane.

Rather than decreasing the air flow when the oxygen is added to the butane system, the air flow can be maintained at the pre-oxygen addition level. The butane feed rate can be increased without reducing yield. In this manner, direct oxygen injection can be used to boost maleic anhydride production.

Direct oxygen injection can also be coupled with air enrichment so that oxygen is added to both the butane feed stream and the air stream. The air flow can either be reduced or maintained at the pre-oxygen addition level. Doing so maximizes the yield and production improvements obtained by oxygen addition.

If oxygen flow is suddenly increased or the reactant feed flow suddenly decreased, it is possible that the output from sparger 26 may move into a detonatable region. To control a sudden increase in oxygen flow, valve 28 is provided with a critical flow orifice which limits the possible oxygen flow. The orifice is sized so that even if valve 28 fails in the full-open state, the amount of oxygen required to produce a detonation under normal minimum feed flow rates cannot be supplied.

During emergency process shutdown, so long as the oxygen flow to sparger 26 is shut down simultaneously with the process reactants, the oxygen flow will be stopped simultaneously with the stoppage of reactant

flow. Since oxygen valve 28 is significantly smaller than either of feed valves 12 and 20, the oxygen flow will stop before the flow of reactants - thereby preventing a feed concentration build-up to a detonatable level.

Controller 40 is operated to shut the oxygen flow to sparger 26 if the feed reactant pressures drop below a certain level. This is because a significant drop in feed-flow can be brought about by feed blockage and a pressure-based shut-down response of valve 28 prevents a possible subsequent detonatable mixture from entering conduit 30.

Additionally, controller 40 is operated to shut the oxygen flow to sparger 26 if the temperature of the mixed oxygen reactant stream goes above a certain level. This is because a significant increase in gas mixture temperature can be brought about by a deflagration near the sparger and a temperature-based shut-down response of valve 28 will extinguish such a deflagration.

Valve 28 is also controlled by controller 40 to assure certain minimum oxygen flows to sparger 26. In operation, reactant feed must be prevented from backstreaming into sparger 26. This is prevented by: maintaining an oxygen flow through each sparger jet 60; maintaining a jet velocity that is great enough to prevent a convective or diffusive flow of the reactant feed into sparger 26; and placing the jets on the downstream side of sparger 26. The maintenance of oxygen flow through each sparger jet 60 is accomplished by insuring that the pressure drop across the jets 60 is significantly greater than the pressure drop within sparger 26. To prevent the reactant feed from diffusing into sparger 26, it is preferred that a minimum pressure drop across each jet 60 be at least 1 psi and preferably 10 psi.

Finally, during startup, a nitrogen purge is used to flush sparger 26 of reactants before oxygen flow begins. During shutdown, sparger 26 is flushed of oxygen with a nitrogen purge while maintaining a high enough pressure drop to prevent backstreaming. This is necessary because reactants will flow into sparger 26 after shutdown.

While sparger 26 has been shown in the shape of a ring, other shapes such as concentric rings, crossed straight sections and straight tubing are acceptable. However, each such structure must meet the requirements set forth above with respect to the most preferred embodiment, i.e., the circular sparger configuration shown in Fig. 2. Rather than placing the jets directly on the downstream edge of sparger 26, they can be placed off center, but still on the downstream side. This may be beneficial as it allows for a greater number of jets to be employed.

While the above description has focused on use of the invention in a maleic anhydride production process, other gas phase oxidations that use fluidized beds may also employ the invention (e.g., processes for the production of acrylonitrile, phthalic anhydride synthesis, etc.).

Gaseous reactant stream, such as naphthalene or

orthoxylylene in the form of a gaseous stream, may be used for the oxidative production of phthalic anhydride using the inventive system and process as described herein.

In other embodiments, the production of nicotinonitrile may be produced by reacting 3-methyl pyridine with ammonia in the presence of a catalyst. In yet another embodiment, isophthalonitrile may be produced by reacting metaxylene and ammonia in the presence of a catalyst.

In certain cases, inert gases may be added to either the oxygen or the reactant feed streams to lower the upper fire limit and thus increase the maximum concentration of oxygen allowed in the feed stream.

It should be understood that the foregoing description is only illustrative of the invention. Various alternatives and modifications can be devised by those skilled in the art without departing from the invention. Accordingly, the present invention is intended to embrace all such alternatives, modifications and variances which fall within the scope of the appended claims.

#### Claims

1. A system for providing a mixture of an oxygen-bearing gas and a gaseous reactant stream selected from the group consisting of butane, butene and benzene to a reactor having fluidized beds to produce a maleic anhydride, comprising:
  - a) a source of a first oxygen-bearing gas coupled to said reactor;
  - b) said reactant gas stream;
  - c) a sparger means for entraining a second oxygen-bearing gas into said reactant gas stream;
  - d) a feed means which couples said sparger means to said fluidized bed of said reactor, for introducing said reactant gas stream and entrained second oxygen-bearing gas directly into contact with said fluidized bed; and
  - e) a control means for controlling feed of said second oxygen-bearing gas to said sparger means so as to entrain sufficient oxygen into said gaseous reactant stream at a point of feed injection to maintain an effective amount of oxygen for producing said maleic anhydride.
2. The system as recited in claim 1 wherein said first oxygen-bearing gas is air.
3. The system as recited in claim 1 wherein said second oxygen-bearing gas is oxygen.
4. The system as recited in claim 1 wherein said fluidized bed comprises a catalyst for converting said gaseous reactant stream and oxygen-bearing gas into a maleic anhydride.
5. The system as recited in claim 1 wherein said control means adjusts feeds of gaseous reactants to said reactant gas stream and said second oxygen-bearing gas to assure that a combined said reactant gas stream and second oxygen-bearing gas is maintained above an upper flammability limit.
6. A method for providing a mixture of an oxygen-bearing gas and a gaseous reactant stream selected from the group consisting of butane, butene and benzene to a fluidized bed reactor to produce maleic anhydride, comprising the steps of:
  - a) entraining an oxygen-bearing gas into said gaseous reactant stream;
  - b) feeding said gaseous reactant stream and entrained second oxygen-bearing gas directly into contact with said fluidized bed reactor; and
  - c) controlling feed of said oxygen-bearing gas so as to entrain sufficient oxygen into said gaseous reactant stream at a point of feed injection for maintaining an effective amount of oxygen directed to producing said maleic anhydride.
7. The method as recited in claim 6 wherein said gaseous reactant stream comprises butane, said oxygen-bearing gas is oxygen and said fluidized bed reactor, said method comprising adding a catalyst for converting said butane and oxygen into a maleic anhydride.
8. The method as recited in claim 6 further wherein said controlling step maintains said feed of said gaseous reactant stream and oxygen above an upper flammability limit.
9. The method as recited in claim 6 further wherein said controlling step maintains a combined stream of said oxygen and gaseous reactant stream above an upper flammability limit.
10. A method for providing a mixture of an oxygen-bearing gas and a gaseous reactant stream to a fluidized bed reactor for producing an anhydride, comprising the steps of:
  - a) entraining an oxygen-bearing gas into said gaseous reactant stream;
  - b) feeding said gaseous reactant stream and entrained second oxygen-bearing gas directly into contact with said fluidized bed reactor; and
  - c) controlling feed of said oxygen-bearing gas so as to entrain sufficient oxygen into said gaseous reactant stream at a point of feed injection for maintaining an effective amount of oxygen directed to producing said anhydride.

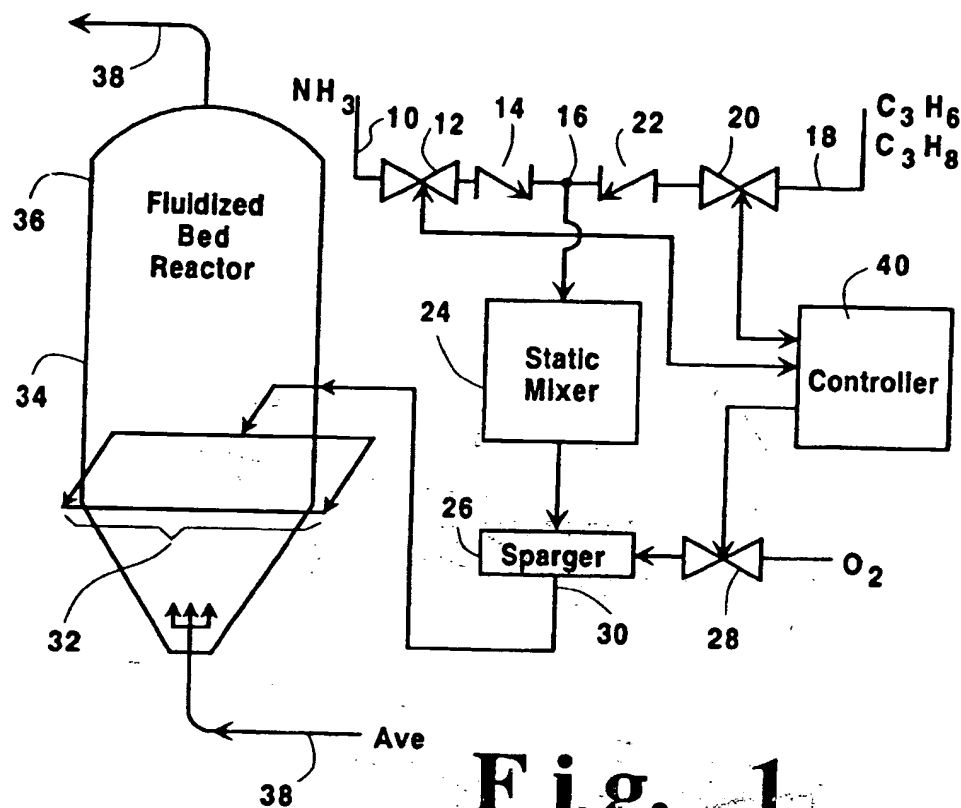


Fig. 1

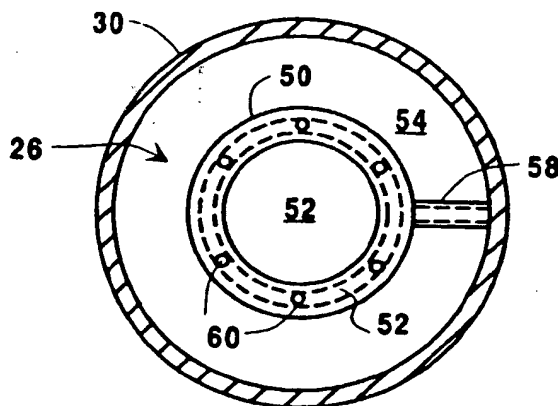
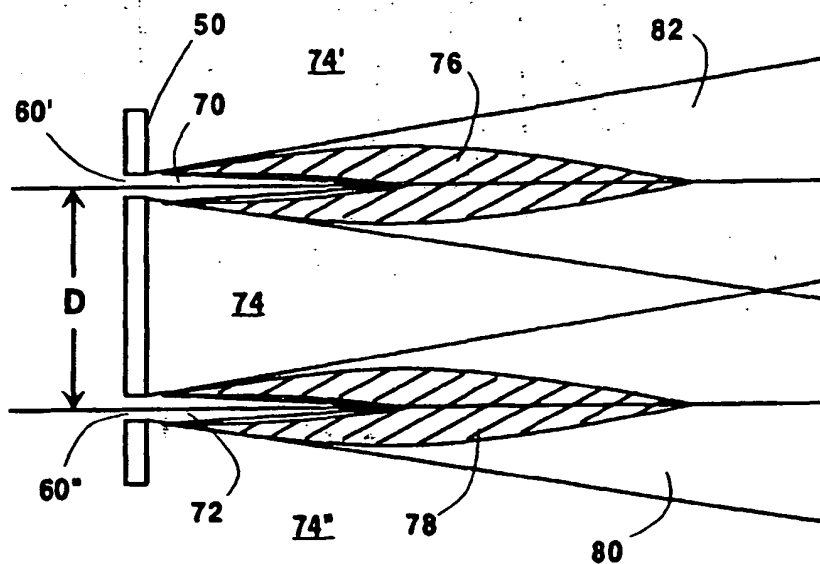


Fig. 2



**Fig. 3**



European Patent  
Office

# EUROPEAN SEARCH REPORT

Application Number  
EP 98 11 1263

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
Y	EP 0 761 298 A (PRAXAIR TECHNOLOGY INC) 12 March 1997 * column 1, line 5 - line 31 * * column 2, line 11 - line 26 * * column 3, line 10 - column 4, line 10 * * column 7, line 7 - line 16 * * claims 8,10 * ---	1-10	C07C51/215 C07C51/25 C07C51/21 C07C57/145 B01J8/24 B01J4/00 B01J8/18 B01J19/00 B01F5/04
Y	EP 0 761 299 A (PRAXAIR TECHNOLOGY INC) 12 March 1997 * column 1, line 5 - line 31 * * column 2, line 11 - line 27 * * column 3, line 8 - line 12 * * column 7, line 5 - line 10 * * claims 1,4-10 * * figure 1 * ---	1-10	
D,Y	US 3 899 516 A (DICKASON ALAN F) 12 August 1975 * column 1, line 49 - column 2, line 30 * ---	1-10	
D,A	US 3 702 619 A (SON JAIME S) 14 November 1972 * column 1, line 10 - line 23 * * column 1, line 58 - column 2, line 10 * * column 7, line 23 - line 65 * * figure 1 * ---	1-10	TECHNICAL FIELDS SEARCHED (Int.Cl.6)  C07C B01J B01F
D,A	US 5 356 213 A (ARPENTINIER PHILIPPE) 18 October 1994 * column 2, line 8 - line 26 * * column 2, line 58 - line 68 * * claim 1 * -----	1-10	
The present search report has been drawn up for all claims			
Place of search <b>THE HAGUE</b>		Date of completion of the search <b>16 September 1998</b>	Examiner <b>Held, P</b>
<p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons &amp; : member of the same patent family, corresponding document</p>			

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